UNITED STATES
DEPARTMENT OF THE INTERIOR

Bureau of Mines

MINE AND WELL EFFECTS EVALUATION

FOR

PROJECT RULISON

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N O T I C E

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Part I

MINE EFFECTS EVALUATION

MINE EFFECTS EVALUATION

FOR PROJECT RULISON

by

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SUMMARY

The mine effects evaluation program for Project Rulison, as carried out by the Bureau of Mines on behalf of the Atomic Energy Commission, was designed to identify, evaluate, and eliminate or control all potential hazards to mining operations in the general project area and to document the effects of the nuclear explosion on such operations.

An initial survey of the general area out to 50 miles from the emplacement well disclosed some 24 coal, oil shale, limestone, and vanadium mines which would be in active or standby status during event time and thus of concern in the effects evaluation program. Such mines were subsequently visited, and the operators were briefed on the general features of the project and its predicted effects on their operations. Recommendations for the evacuation of the mines during event time later were formulated, and preshot and postshot inspections eventually were made of several of the closer mines where structural damage was a possibility.

Postshot inspections indicated structural damage during event time at only two mines--the Cameo and Red Canon coal mines at 27 and 32 miles respectively from the shot point. The rather extensive damage at Cameo reasonably could be attributed to the Rulison event, while the relatively minor damage at Red Canon may or may not be. Except for small landslides and isolated rock falls along certain access roads, no significant damage attributable to Rulison was observed at any of the other nearby mines inspected; nor was any reported by the operators of the fringe-area mines subsequently contacted.

Effects of the Rulison event on the closer mines were somewhat less, and on the farther mines somewhat more, than had been expected from predicted ground motions. Azimuthal variations in the ground motion may account for most of these effects, but the lack of adequate damage criteria also could be a significant factor. Better criteria obviously were needed for relating ground motion to mine damage, and more restrictive safety measures were suggested for future shots until such criteria became available.

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Mine damages on the order of those experienced from the Rulison event would be expected from any future shot of the same yield. Nevertheless, the cumulative effects from a multitude of shots in this range could increase the overall damage potential. Both the severity and extent of such damages, of course, would tend to increase with the yield. Thus any escalation of the yield not only would cause greater damages to the affected mines but also could initiate damages at some of the closer but unaffected operations.

INTRODUCTION

Historical Description[2/]

Project Rulison is a joint experiment sponsored by Austral Oil Company Incorporated, Houston, Texas, the U.S. Atomic Energy Commission and the Department of the Interior, with the Program Management provided by CER Geonuclear Corporation of Las Vegas, Nevada, under contract to Austral. Its purpose is to study the economic and technical feasibility of using underground nuclear explosions to stimulate production of natural gas from the low-productivity, gas-bearing Mesaverde Formation in the Rulison Field.

The nuclear explosive for Project Rulison was detonated successfully at 3:00 p.m. ±0.1 seconds Mountain Daylight Time, September 10, 1969, at a depth of 8,425.5 feet below ground level and was completely contained. Preliminary results indicate that the Rulison device behaved about as expected; i.e., with a yield of 40(-4 to +20) kt. The wellhead of the emplacement well, Hayward 25-95A, is at an elevation of 8,154 feet above mean sea level (msl) and is located 1,976.31 feet east of west line and 1,813.19 feet north of south line of Section 25, Township 7 South, Range 95 West of 6th P.M., Garfield County, Colorado, which corresponds to geodetic coordinates of longitude 107°56'53" West and latitude 39°24'21" North.

Program Objectives and Procedures

This report covers the mine effects evaluation program for Project Rulison as carried out by the Bureau of Mines on behalf of the Atomic Energy Commission. Purpose of this program was to identify, evaluate, and eliminate or control all potential hazards to mining operations in the general project area and to document the effects of the nuclear explosion on such operations. The several phases of the program were carried out by the Denver Mining Research Center of the Bureau of Mines under the authorization and financial support of the Nevada Operations Office of the Atomic Energy Commission.

2/ Official description provided by the U.S. Atomic Energy Commission

The subject program involved a variety of office and field investigations conducted intermittently throughout 1969. Initially, the general project area out to 50 miles from the emplacement well was surveyed for any active mines or mineral plants that might be affected by the planned nuclear experiment. All such mineral developments disclosed by the survey subsequently were visited, and the operators were briefed on the general features of the project and its predicted effects on their operations. Recommendations for the evacuation of mines in the general area during event time later were formulated, and preshot and postshot inspections evnetually were made of several of the closer mines where structural damage was considered a possibility. Supplemental postshot inspections ultimately were required to evaluate claims for damages to other more distant mines.

GENERAL SETTING

Site of the nuclear stimulation project was the Rulison natural gas field in the Colorado River Valley of west-central Colorado. U.S. Highways 6 and 24 (Interstate Route 70) and the main line of the Denver and Rio Grande Western Railroad follow the Colorado River across the general project area between the towns of Glenwood Springs and Grand Junction. Glenwood Springs is 35 airline miles east, and Grand Junction is 40 airline miles southwest, of the site. Surface Ground Zero (SGZ) for the experiment was on the northern flanks of Battlement Mesa, some 3,000 feet above and 5 miles south of the river--specifically at an elevation of 8,154 feet in NE/4SW/4 sec. 25, T.7 S., R.95 W., 6th PM, Garfield County, Colo. (See accompanying map of general project area.) Ground Zero for the nuclear detonation was 8,425 feet below the surface, in gas-bearing shales and sandstones of the Mesaverde formation.

Major topographic features within the general project area include the Grand Hogback and Huntsman Hills along the northeastern and eastern edges, Battlement and Grand Mesas south of the Colorado River, and the Roan or Green River Plateau in the northwestern sector. Lands west of the Grand Hogback are in the Colorado Plateau Physiographic Province and represent a dissected plateau with strong relief. Elevations range from nearly 5,000 feet in the main drainage valleys to more than 11,000 feet on the erosional remnants of the higher mesas.

The area is on the southern flank of the Piceance Creek Basin, a major structural and sedimentary basin extending diagonally across northwestern Colorado. Sedimentary cover in the basin has an aggregate thickness of over 20,000 feet. Uplifting of the White River Plateau and Elk Mountains steeply tilted the pre-Tertiary strata along the eastern and southern margins of the basin. Similar but less severe tilting of these strata resulted from the Uncompahgre uplift on the

west. The Tertiary sediments deposited contemporary with the structural downwarping of the basin are more nearly horizontal, exhibiting a regional dip and general thickening toward the center of the basin. The Mesaverde formation of Late Cretaceous age crops out around the interior edges of the basin, while the Tertiary Wasatch and Green River formations cover most of the project area within the basin. Green River strata overlie most of the basin north of the Colorado River, and erosional remnants of this formation are preserved below the lava capping of Battlement and Grand Mesas. The principal mineral resources of the area -- coal, natural gas, and oil shale--are confined to the Upper Cretaceous and Tertiary strata, largely the Mesaverde and Green River formations.

MINES IN PROJECT AREA

The preliminary mineral industry survey of the Rulison project area disclosed some 24 mines and 9 mineral plants within a radius of 50 miles of SGZ, all of which would be in an active or standby status during the event time and thus of concern in any effects evaluation program. Relative locations of such mines and plants are shown on the map of the general project area that accompanies this report (figure 1). Inasmuch as the mineral industry plants in the general area were evaluated under the structural effects program for the project, they will not be considered further here.

By far, the largest number of active or semi-active mineral operations in the project area are coal mines. Several coal fields of the Uinta Coal Region of eastern Utah and western Colorado -- Danforth Hills, Grand Hogback, Carbondale, Somerset, Grand Mesa, and Book Cliffs -- occur around the southern flanks of the Piceance Creek Basin. Most of these fields are 25 to 40 miles from SGZ; only a part of the Grand Hogback field is closer than 25 miles. The coal, which is confined largely to the lower part of the Mesaverde formation, has been mined in the several surrounding fields for many years. Although many of the older mines have been worked out and abandoned, a number of operations are still active in each field. Coal beds within the various fields range from horizontal to steeply pitching and contain both strong and weak caprock. Some beds are relatively free of gas, while others are moderately to extremely gassy.

More than 400 persons are employed in the 17 active coal mines in the project area. Miners at all but the smaller operations generally are unionized, and most are members of District 50 - United Mine Workers of America.

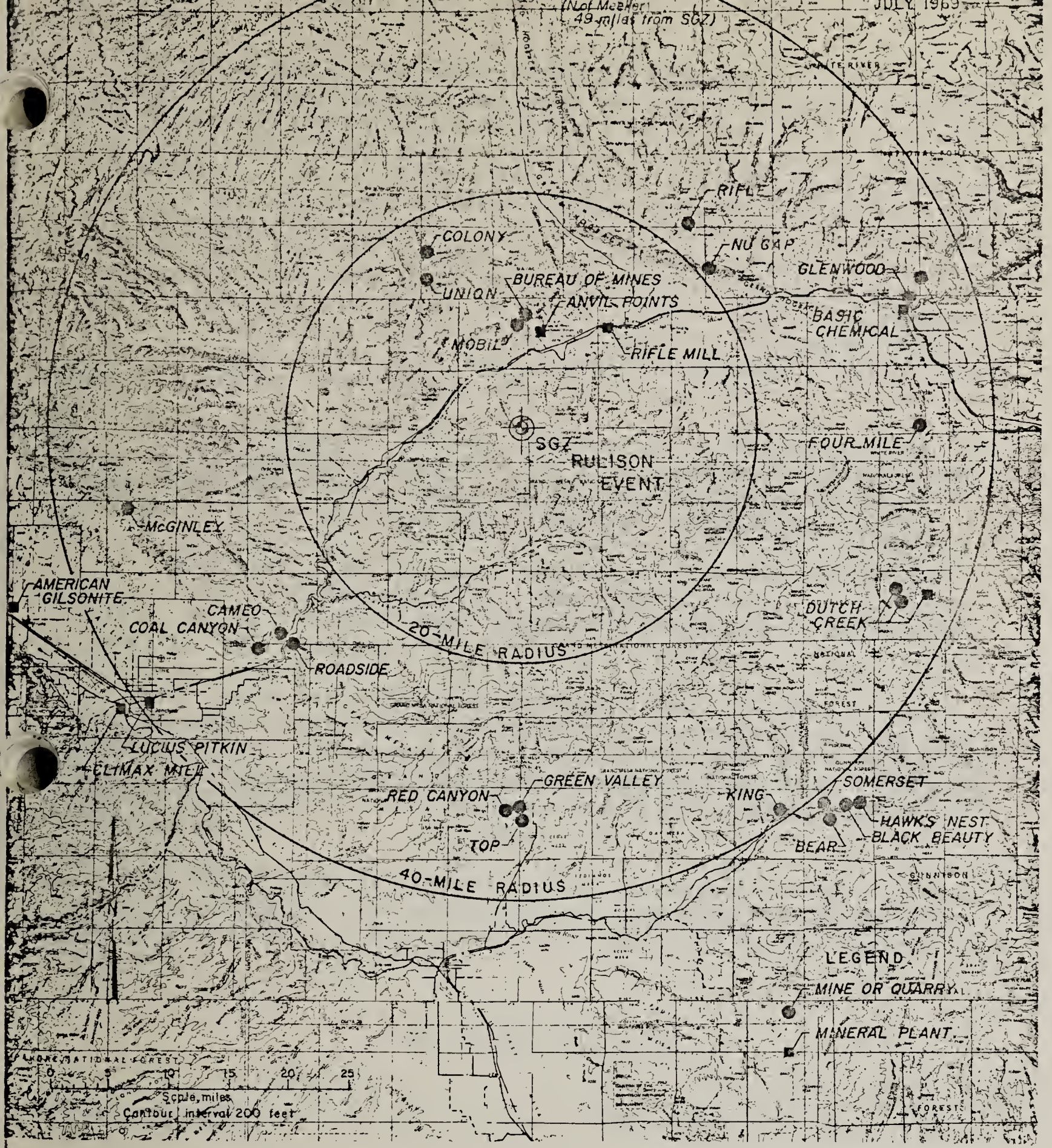

FIGURE 1.–Mines and Mineral Plants In Vicinity of AEC Rulison Event

Over the years, five experimental or demonstration mines have been opened in the so-called oil shales of the Green River formation within the project area north of the Colorado River. Such mines lie at distances of 8 to 17 miles north of SGZ, in the sector between Rulison and Grand Valley. The old Rulison mine, which is closest to SGZ, represents an early day operation and is considered abandoned. All of the others are more recent developments, largely inactive at present, but subject to periodic operation for research and experimental purposes. Typical mine development is by means of drift entries into the nearly verical oil shale escarpments high above the valley bottoms. Horizontal room-and-pillar mining methods have been used exclusively. The wide mine openings and steep surface topography that are characteristic of such operations present a variety of ground control problems.

The well known Rifle Creek vanadium mine is developed in the massive Entrada and Navajo sandstones at a point some 23 miles northeast of SGZ where these older Jurassic and Triassic formations are downwarped in the prominent monocline of the Grand Hogback.

The only other active operations of any concern in the project area are two limestone quarries in the Glenwood Springs area some 35 miles from SGZ. Both are small summertime operations in the massive Leadville limestone formation of Mississippian age.

Four active sand and gravel pits and plants, 40 miles or more from SGZ, were considered in no danger from the project and thus were eliminated from further consideration under the effects evaluation program. The numerous other long-inactive and abandoned mines within the project area likewise were considered beyond all possible benefits of the program.

Additional pertinent features of all the recently active coal, oil shale, limestone, and vanadium mining operations in the project area are included with the mine effects tabulation in the appendix of this report.

MINE EFFECTS EVALUATION

Mine Evacuation

Recommendations for the evacuation of mines at Rulison event time were based on predictions of ground motion as well as on observed and reported conditions and age of the individual mine workings. Any damage to the mines in the area during event time, of course, would present a potential hazard to persons working in these mines. Then, too, greater caution was warranted where personal safety was involved

and all the contingent factors could not be resolved. In order to provide the necessary safety factors without an undue overreaction, the aerial extent of all possible damage to mine workings and facilities was equated to the threshold of perceptible ground motion. Such threshold was assumed equivalent to a peak particle acceleration of about 0.01 gravity unit which, according to preliminary predictions, would be experienced within a range of about 28 to 35 miles, depending upon the yield of the nuclear device.

It was recommended therefore, that all 8 active or standby mines within the minimum range of 28 miles from SGZ be evacuated of personnel during event time. For practical purposes, the Coal Canyon mine at 29 miles was considered with the latter group. Special conditions and considerations also warranted the evacuation of the Dutch Creek coal mines some 7 miles beyond this minimum range.

There were 7 other active mines in the 28-to-35-mile range, and another 6 such operations within 35 to 50 miles, for which evacuation was not considered necessary. Nevertheless, it was recommended that the operators of all these fringe area mines be officially alerted to the date and time of the event so as to be prepared for discretionary voluntary evacuation. No objection was raised to the official evacuation of any of the fringe area mines for acceptable reasons, technical or otherwise.

The Atomic Energy Commission Director of Nuclear Operations ultimately decided to evacuate all the active mines in the general area during event time. This decision was largely in response to labor union demands for lengthy paid holidays during event time. It also eliminated any preferential or descriminatory treatment between the large and small, or union and non-union, operations. Responsibility for coordinating the evacuation of all mine personnel throughout the area during event time was assigned to CER Geonuclear Corp. As far as could be determined, total evacuation was accomplished.

Preshot and Postshot Mine Inspections

In the absence of other criteria, the threshold of perceptible ground motion (about 28 miles from SGZ) also was used to establish the limits for preshot and postshot inspections of possible mine structural damage.

Preshot inspections of 7 active or standby mines within the 28-mile range were made during the period August 21 to September 3, 1969. Postshot inspections of these same mines were made as soon as possible after the event, or during the period September 11-17, 1969. Only two of the active or standby mines originally disclosed within this maximum effects range were not inspected. No inspections of the Mobil oil shale mine were attempted because of the security restrictions

insisted on by the operator. The planned inspections of the Coal Canyon strip mine proved neither warranted nor feasible inasmuch as the operations terminated before event time and the access road had since been washed out by flash floods.

A non-scheduled postshot inspection of the Red Canon coal mine at 32 miles from SGZ was made September 13, 1969, upon receipt of a damage report from the operator. At the request of the Project Rulison Claims Office, special postshot damage investigations also were made of the Busk-Ivanhoe (Carlton) water tunnel on October 7th and of the Carter gold mines on November 10th and 11th. Both of these semi-active operations were well outside the general project area--the tunnel some 80 miles east, and the mines some 93 miles southeast, of SGZ. Special mine damage inspection reports were prepared in four cases where claims for damages resulting from the Rulison event were investigated.

The various preshot and postshot examinations within the general project area were made with one or more of the Bureau's Coal Mine Inspectors--principally Vernon A. Bowling of Grand Junction. Oscar T. Rice, Deputy State Coal Mine Inspector from Paonia, assisted in the examination of the Roadside and Cameo coal mines. Fred L. Smith of Denver, a consulting mining engineer engaged by CER Geonuclear at the request of the operators, also participated in the examinations of these latter two mines. A representative of the operator was present during all preshot and postshot examinations except those at the Roadside coal mine and the inactive Bureau of Mines oil shale mine. Preshot and postshot photographs were taken of the most critical areas in each mine inspected. All apparent damage to the mine workings and facilities from the event also were photographed. Operators of most of the fringe-area mines not formally examined were contacted subsequent to the Rulison event concerning the perceptible ground motion and its effect, if any, in their general areas.

Mine Structural Damage

The postshot inspections indicated damage during event time at only two mines--the Cameo and Red Canon coal mines at 27 and 32 miles respectively from SGZ. The rather extensive structural damage at Cameo reasonably could be attributed to the Rulison event, while the relatively minor damage at Red Canon may or may not be. There was no evidence of any new roof falls in the Bureau of Mines oil shale mine (10 miles from SGZ) where several large falls have occurred in the past and minor falls occur periodically. A small chunk of coal about 6 inches in diameter dropped from the roof of the new lower level of the Nu-Gap coal mine (20 miles from SGZ) but caused no damage. An isolated timber prop supporting power cables along the main entry of the Roadside coal mine (27 miles from SGZ) also was toppled during event time, but such damage was readily remedied and could hardly be rated compensable. No damage attributable to the Rulison event was observed in any of the other nearby mines examined, nor was any re-

ported by the operators of the fringe-area mines subsequently contacted. However, small landslides, isolated rock falls, and minor slumping of earth fill sections were observed or reported along mine access roads, particularly those traversing the steeper and less stable canyon slopes.

Other pertinent information from the postshot inspections of the nearby mines and from the operators of the fringe-area mines not inspected is summarized in tabular form in the appendix of this report. Selected preshot and postshot photographs of the more critical sections of the mines inspected also are included there. Photographs of the confirmed damages in the Cameo and Red Canon mines, and of the reported but unsubstantiated damages in other mines, are included with the brief descriptions of such damages given below.

Cameo mine — The coal bed in the Cameo mine is overlain by about a foot of carbonaceous mudstone, some two feet of soft jointed sandstone, and a rider seam of coal a few feet thick. This roof strata, particularly the mudstone caprock, is unstable and subject to frequent failures in sections of the mine. In the shallower workings near the outcrop, the roof strata contains prominent vertical fractures which begin to open as soon as the coal is mined. Subsequent strata separations along bedding planes permit the roof to sag and eventually to collapse, often in spite of the normal mine supports.

Most of the mine roof spans are reinforced by 3-foot roof bolts anchored in the jointed sandstone above the caprock. Wooden crossbars, held against the caprock by both roof bolts and timber posts, generally are installed along the main entries. In many places, the caprock breaks into small plates which drop out and reduce tension on the roof bolts. Many bolt anchors also are prone to slip. As a result, the reinforced roof span begins to sag, initiating new tension cracks and bedding separations and insuring ultimate roof failure unless timber props are installed.

Locally near the coal outcrop, the original roof strata was eroded away by ancient streams and later replaced by loosely cemented gravel and boulders. Such material generally caves to a height of several feet above any coal mined below it, necessitating extensive cribbing, lagging, and other timber support.

Most of the structural damage disclosed by the postshot inspection and attributed to the Rulison event, was confined to working areas under shallow cover, close to the outcrop--specifically the 1st Southwest section and the Nos. 1 and 2 Outside entries. In these areas of poor to bad roof, new cracks in the caprock were formed, and some of the old existing cracks were enlarged. (See figures 2 to 5.) A small roof fall also occurred along one entry, and the resulting separation of the roof strata adjacent to this fall placed excessive weight on several successive timber sets in the entry. (See figures 6 and 7.)

Fig. 2 - New 3/8-in by 30-ft crack in caprock along No. 1 Outside entry at 4th crosscut.

Fig. 3 - New 1/2-in by 40-ft crack in caprock along No. 1 SW entry outby No. 1 Outside entry.

Fig. 4 - New 1/4-in by 150-ft crack in caprock along No. 2 SW entry at 1st crosscut.

Fig. 5 - New 1/2-in crack in caprock along No. 1 SW entry between 1st and 2nd crosscuts.

Fig. 6 - Strata separations in newly caved roof section outby face of No. 2 Outside entry.

Fig. 7 - New roof fall and damaged timber supports outby face of No. 2 Outside entry.

Necessary repairs to this section of the mine, as determined by the consultant engaged at the request of the operator, involved the removal of 4 damaged timber sets, the cleanup of some 9 cubic yards of fallen rock, and the installation of 25 new timber sets along 150 feet of entry. The operator subsequently submitted a damage claim for cleaning up the fallen rock and systematically timbering 1,000 feet of entry with 200 timber sets plus 2 intersections with 6 sets. No reconciliation between the consultants' determination and the operator's claim had been made by the date of this report.

The development of numerous small new cracks in the caprock and the enlargements of existing cracks also were noted in the "A" Raise section of the mine. This latter section is more than a mile from the coal outcrop and has a relatively good roof, but lies below a slender erosional remnant of rock that extends some 1,000 feet above the general ground level. The damage here was not considered severe enough to require additional timber supports and therefore, probably is not compensable. The operator made mention of this damage, but did not claim compensation for it. Two other sections of the mine--one with relatively good roof conditions (2nd East panel) and the other with very poor conditions (3 West haulage entry)--suffered no observable damage from the event.

Red Canon mine — The shale roof in the Red Canon coal mine is structurally quite stable and has stood for years supported only by timber props. However, even this roof stone begins to sluff in time, and relatively small thin slabs periodically drop from the roof throughout the mine. Such rock is often left where it falls, but may be stacked by hand behind the timber props along the slides of the travel and haulageways.

The special postshot inspection of this mine revealed that an aggregate of about 1/2 cubic yard of the shale caprock had recently fallen from the roof in four isolated sections of the workings. (See figures 8 to 11.) The most serious fall occurred midway along the inclined return airway where a thin slab, about 4 feet by 2 1/2 feet in area, had dropped onto the electrical power cables serving the mine. In dropping, this slab tore loose the power cables from their insulated hangers on two adjoining timber props. The cleanup of all the recently fallen rock and the rehanging of the power cables were estimated to require about 1/2 man-shift.

Busk-Ivanhoe (Carlton) tunnel — This 9,400-foot tunnel was driven through the Precambrian granite core of the Continental Divide before the turn of the century. Originally a railroad tunnel, it is now used exclusively for water diversion. The tunnel has a long history of cave-ins and is heavily timbered throughout

Fig. 8 - Thin slab of caprock down on power cables in return airway.

Fig. 9 - Caved caprock (darker material on top of old cave) in level entry east of shaft.

Fig. 10 - Caved caprock (by lamp and on shaker pan) in level entry east of shaft.

Fig. 11 - Caved caprock (darker material in foreground and below lamp) in old room from level entry east of shaft.

its length. Most of the original tunnel supports have long since deteriorated, but only part of these have been repaired or replaced.

A major cave-in of about 130 cubic yards of rock and timber at 4,200 feet from the east portal, plus minor rock and timber falls at four other locations, was reported to have occurred sometime between September 9th and 15th. (See figures 12 to 14.) Investigations indicated that the major cave-in could have coincided with the Rulison event, but that the minor rock and timber falls may not have. No ground motion was felt in the immediate area, and such motion as could be projected for the area probably was too low to have caused the damage. Any consideration of the past history of the tunnel and its present physical condition leaves little doubt that the cave-in would have occurred sooner or later, irregardless of the Rulison event.

Carter mine — Damages to the Carter and two other contiguous gold mines, consisting of caved adit portals in alluvium and caved drifts below old shrinkage stopes, also were reported as resulting from the Rulison event. (See figures 15 and 16.) An inspection revealed nothing conclusive that would tie this damage to Rulison. About all that could be determined was that it probably was of recent origin. The sections of the mines found damaged were those most susceptible to natural cave-ins. Considering the age of the workings, the conditions of the old timbers, and the altered nature of the Precambrian granite and schist wall rock, such cave-ins would be expected to occur periodically at any time. It was concluded that the damages reported were of natural origin and not related to the Rulison event.

Monte Queen mine — The operator of this silver mine, some 102 miles south of SGZ, near Lake City, reported that about 25 tons of loose rock was dislodged from a working face during event time. An inspection was not made inasmuch as no compensable damages to mine workings or machinery were claimed. The mine workings reportedly are along an "active" fault-fissure in the Eureka rhyolite (a Tertiary volcanic flow). As far as can be determined, there are no fault structures extending from the general project area into the Lake City area, and it is unlikely that sufficient ground motion was experienced here to have caused the reported rock fall.

Fig. 12 - West end of major cave-in at 4200 ft.

Fig. 13 - East end of major cave-in at 4200 ft.

Fig. 14 - Disintegrated wall plate toppled post, and sagged arch segment of old tunnel set at 4055 ft.

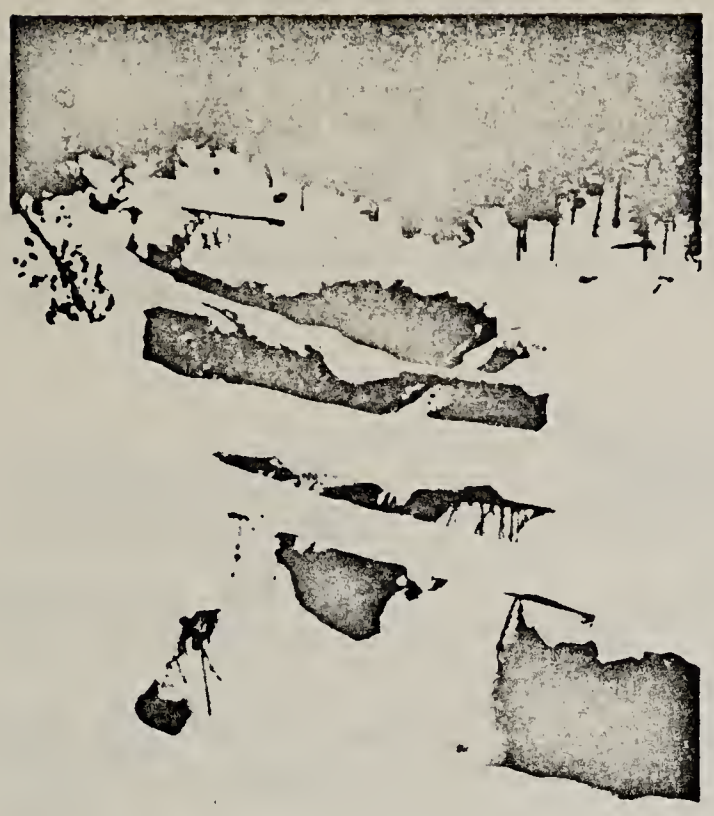

Fig. 15 - Caved portal of No. 2 level of Golden Islet mine.

Fig. 16 - Caved portal of No. 3 level of Golden Islet mine.

GROUND MOTION

A comparison of predicted and observed ground accelerations at several seismic recording stations near certain mines in the project area is tabulated below. The actual yield of the Rulison device has not been announced, but for comparison purposes, is assumed to be the design yield of 40 kilotons.

Miles and direction from SGZ	Seismic station and nearby mines	Peak surface particle acceleration, g (Predicted)	(Observed)
9 N	MOBIL-Mobil and USBM oil shale mines	0.116	0.056
21 NE	HARVEY GAP-Nu-Gap coal and Rifle vanadium mines	0.023	0.031
27 SW	CAMEO-Cameo and Roadside coal mines	0.015	0.038
34 S	CEDAREDGE-Red Canon, Top and Green Valley coal mines	0.009	0.007
35 ENE	GLENWOOD-Four-Mile coal mine, two limestone quarries	0.009	0.005
41 SSE	PAONIA-King, Somerset, Bear, Black Beauty and Hawk's Nest coal mines	0.006	0.011
44 N	MEEKER-Rineau coal mine	0.006	0.004

The duration of the ground motion recorded at the above stations ranged from 19 to 80 seconds. Wide and disproportionate variations occurred between the individual stations, but a pronounced overall increase in the duration of motion with distance from the shot point was apparent.

The measured frequency of the maximum ground motion recorded at the above stations ranged from 3.0 to 8.3 Hz and averaged about 5.6 Hz.

The peak accelerations recorded at the majority of the seismic stations throughout the area were somewhat higher than had been predicted. However, both higher and lower peak amplitudes were observed at the few stations strategically located with respect to the mines in the area. At the Cameo mine, where significant damage occurred, the observed peak acceleration of 0.038 g was 253 percent of the predicted peak amplitude. Minor damage occurred in the Red Canon mine at a peak acceleration of only 0.007 g -- a mere 78 percent of the predicted value.

Unlike the predictions, the observed ground motions did not attinuate proportionately with distance in all sectors of the project area. Instead, the seismic radiation pattern was roughly elongated in an east-west direction and generally corresponded to the outline of the basin. Although not fully understood, such azimuthal variation probably is the result of changes in the geological and geophysical character of the rock media from sector to sector.

Seismic experience from the Rulison event extended the arbitrary threshold of perceptible ground motion to about 37 and 52 miles, respectively, for peak accelerations of 0.01 and 0.005 g. These distances compare to the radius of 28 miles for peak accelerations of 0.01 g, which was used in planning the mine effects evaluation program on the basis of preliminary ground motion predictions for a 40-kiloton yield.

CONCLUSIONS

Effects of the Rulison event on the closer mines were somewhat less, and on the farther mines somewhat more, than had been expected from the predicted ground motion. The unpredicted azimuthal variations in ground motion attenuation about the shot point could account for most of these effects, although the lack of adequate mine damage criteria is doubtless a contributing factor.

Better criteria obviously is needed for relating ground motion to mine damage, particularly in the near perceptible range and for old deteriorated workings in bedded strata having wide roof spans and poor-to-bad roof conditions — such as apply to most mines in the project area. Just how these and the variety of other unique mine and geologic features react to ground motion of specific magnitude, duration, and frequency is largely unknown.

A greater safety factor for the limits of both mine evacuation and potential structural damage should be applied until the parameters of all the variables needed for accurate predictions are known. Use of the threshold of perceptible ground motion for the limits of both structural damage and personnel evacuation still appears justified. However, a threshold value of 0.005 g peak acceleration for the highest predictable yield probably would be more appropriate, considering the multitude of unknown factors.

Apparent mine damage was experienced from peak ground accelerations of 0.038 g and 0.007 g, at distances of 27 miles and 32 miles, respectively, from SGZ. Damages on the order of those occurring here certainly could be expected from any future nuclear shots of the same yield. The cumulative effect from a multitude of shots in this range, of course, would increase the overall damage potential.

The lack of suitable damage criteria precludes any definite conclusions regarding the effects of future shots of greater yield on the mines in the area. Mine damage results solely from the ground motion produced by the nuclear detonation which, in turn, is a function of the yield as well as other factors. The conceivable doubling or trippling of the Rulison yield would be expected to increase the observed peak accelerations by less than 50 percent and 100 percent, respectively. It is assumed that mine damage from such higher yields would increase in this same order of magnitude. The radius of potential mine damage also would be extended a like amount. Thus some of the closer mines that survived the initial shot unharmed could be to show structural damage. A few of these mines actually fell within the arbitrary limits of potential damage from the initial Rulison event, and it is possible that not all of the effects from that shot were immediately apparent. Damages such as hidden fractures and strata separations may not show up for long periods. Future shots of greater yield also would tend to increase the severity and extent of landslides which could block access roads along the steeper canyon slopes and thus curtail some mining operations.

Natural gas and atomic energy are the principal competitors of coal in the total energy field. Even if it were not their own mines that were being shaken up, opposition from the coal mine operators and unions would be expected to increase in proportion to the number and size of the nuclear explosions that are attempted.

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APPENDIX TO PART I - MINE EFFECTS EVALUATION

Tabulation - Effects of Rulison event on mines in vicinity.

Selected preshot and postshot photographs of mines inspected for Rulison effects evaluation program, showing condition of workings and facilities. (Note: All photographs taken under this program are on file at the Denver Mining Research Center.)

EFFECTS OF RULISON EVENT ON MINES IN VICINITY

Miles and direction from SGZ	Mine	General Features	Ground Motion	Observed or reported damage/other comments
9 N	MOBIL oil shale	Experimental room-and-pillar mining (1964-68). High, wide rooms with poor to fair roof.	Strong	No damage to mine. Surface effects same as USBM mine below.
10 N	USBM oil shale	Experimental room-and-pillar mining (1945-56). High, wide rooms with poor to fair roof.	Strong	No damage to mine. Rock slide and slump cracks on access road. Small rocks dropped from cliff above mine yard. Slide raised dust east of mine.
15 NNW	UNION oil shale	Experimental room-and-pillar mining (1956-59). High, wide rooms with fair to good roof.	Moderate to strong	No damage to mine. Small rock falls along access road.
17 NNW	COLONY oil shale	Experimental room-and-pillar mining (1964-68). High, wide rooms with fair to good roof.	Moderate to strong	No damage to mine. Small slide on mine road. Rocks fell from canyon walls and dust raised. Autos rocked.
20 NE	NU-GAP coal	Small truck mine being developed from outcrop of steeply pitching coal seam in Grand Hogback.	Moderate	No damage to mine. Chunk of coal dropped from roof. Loose soil ran down surface cut at portal. Power cables swayed.
23 NE	RIFLE vanadium	Open room-and-pillar retreat mining (pulling pillars) in pitching massive sandstone	Moderate	No damage to mine. No increase in radio-activity. Extensometers showed no permanent strata separation. Power cables swayed.

EFFECTS OF RULISON EVENT ON MINES IN VICINITY

Miles and direction from SGZ	Mine	General Features	Ground Motion	Observed or reported damaged/other comments
27 SW	CAMEO coal	Open room-and-pillar mining in flatly-pitching seam with generally poor to bad roof. New workings under shallow cover, near outcrop.	Moderate to strong	Small roof fall with strata separation, damaged timber sets, and extensive cracking of caprock. New workings near surface showed most damage.
27 SW	ROADSIDE coal	Mining same seam as Cameo but with less cover and better roof. Air intake and return badly deteriorated.	Moderate to strong	No damage except for toppled timber prop in main entry. Large rim-rock boulder reportedly dislodged southwest of mine.
29 SW	COAL CANYON	Auger mining in coal outcrop below high bank with loose rock above.	---	Not inspected and no report as mine closed and road washed out prior to event time.
32 S	RED CANON coal	Small truck mine in pitching seam with fairly stable roof. Portal and tipple sound.	Slight	Small roof falls aggregating about 1/2 cu. yd. in 4 areas of mine. Loose tin on roof of tipple rattled.
32 S	GREEN VALLEY coal	Small truck mine in pitching seam with only fair roof. Portal sound.	Not perceptible	No damage to mine or surface plant.

EFFECTS OF RULISON EVENT ON MINES IN VICINITY

Miles and direction from SGZ	Mine	General Features	Ground Motion	Observed or reported damage/other comments
33 S	TOP coal	Small truck mine in pitching seam with fair to good roof. Portal sound.	Not perceptible	No damage to mine or surface plant. Table in nearby home rattled.
34 WSW	McGINLEY coal	Small truck mine in narrow canyon with loose rim-rocks.	Not perceptible	No damage to mine or surface facilities. Barely perceptible at home in Fruita.
34 E	FOUR-MILE coal	Small truck mine in steeply-pitching seam in hogback. Portal sound.	---	No report.
35 ESE	DUTCH CREEK coal	Two large adjoining mines on pitching seam--both extremely gassy and subject to ground "bumps".	Not perceptible	No damage to mine and no excessive gas released.
35 ENE	BASIC CHEMICAL lime	Small limestone quarry worked in summer season with contract crew.	---	No report. Barely perceptible in Glenwood Springs. Some cars rocked.
35 ENE	GLENWOOD lime	Small limestone quarry worked in summer season with contract crew.	---	No report. Barely perceptible in Glenwood Springs. Some cars rocked.
40 SE	KING coal	Gassy mine on flatly-pitching seam with poor roof. Portal and tipple sound.	Barely percept.	No damage in mine. Surface tipple rattled.

EFFECTS OF RULISON EVENT ON MINES IN VICINITY

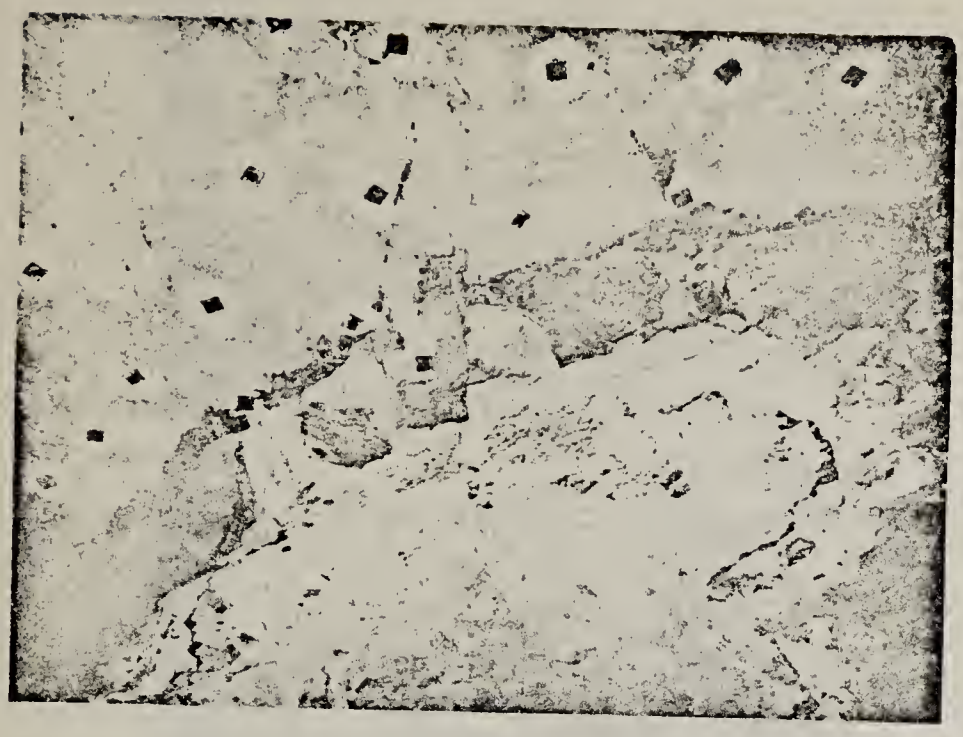
Miles and direction from SGZ	Mine	General Features	Ground Motion	Observed or reported damage/other comments
41 SE	SOMERSET coal	Large slope mine on 2 seams, 40 ft. apart--both gassy with bad roof.	Barely percept.	No damage to mine or plant. Coin balanced on mine rail not disturbed.
42 SE	BEAR coal	Medium-size gassy drift mine with poor roof, sound portal.	Barely percept.	No damage to mine.
43 SE	BLACK BEAUTY coal	Small slope mine. Flimsy tipple on steep slope with loose rocks.	Not perceptible	No damage to mine and no rock falls from slope above tipple.
43 SE	HAWK'S NEST coal	Small mine on flatly-pitching seam with average roof. Old but sound tipple on slope with loose rocks.	Not perceptible	No damage to mine. No rock dust shaken onto previously cleaned conveyor belt in main entry. Table in nearby home rattled slightly.
49 N	RINEAU coal	Small drift mine with average roof, sound portal and tipple.	Not perceptible	No mine damage and no rock falls on surface. Bottles rattled in Meeker Hotel.
64 NW	WHITE RIVER coal	Small slope mine with average roof, some 5 miles SE of Rangely.	Not perceptible	No damage to mine. Some persons in Rangely reportedly felt tremor.

EFFECTS OF RULISON EVENT ON MINES IN VICINITY

Miles and direction from SGZ	Mine	General Features	Ground Motion	Observed or reported damage/other comments
79 E	BUSK-IVANHOE water tunnel	9400-ft bore through granite core of Continental Divide west of Leadville.	Not perceptible	Major cave-in reported, but not substantiated, as resulting from Rulison event.
93 SE	CARTER gold	Several old contiguous mines in Gold Brick District ENE of Gunnison.	Not perceptible	Caved adit portals and level drifts claimed, but not substantiated as caused by event.
102 SSE	MONTE QUEEN silver	Mine, about 1 mile S of Lake City, reported on "active" fault-fissure in Eureka rhyolite.	Barely percept. (?)	25 tons rock reported dislodged from working face during event time. Not investigated, but considered unlikely on basis of insufficient ground motion.

Cliffside portal of mine adit

Old office and shop buildings in mine yard along cliff face



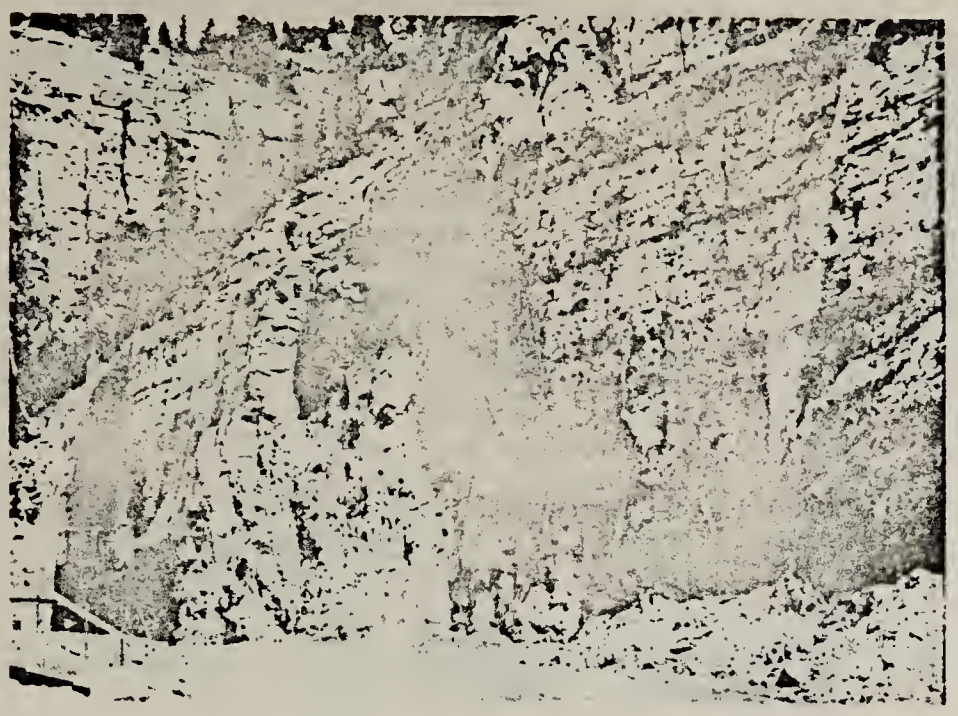
Loose rock hanging from roof bolts at edge of major roof fall area

Fractured corners of 27-ft-high pillars along upper haulageway

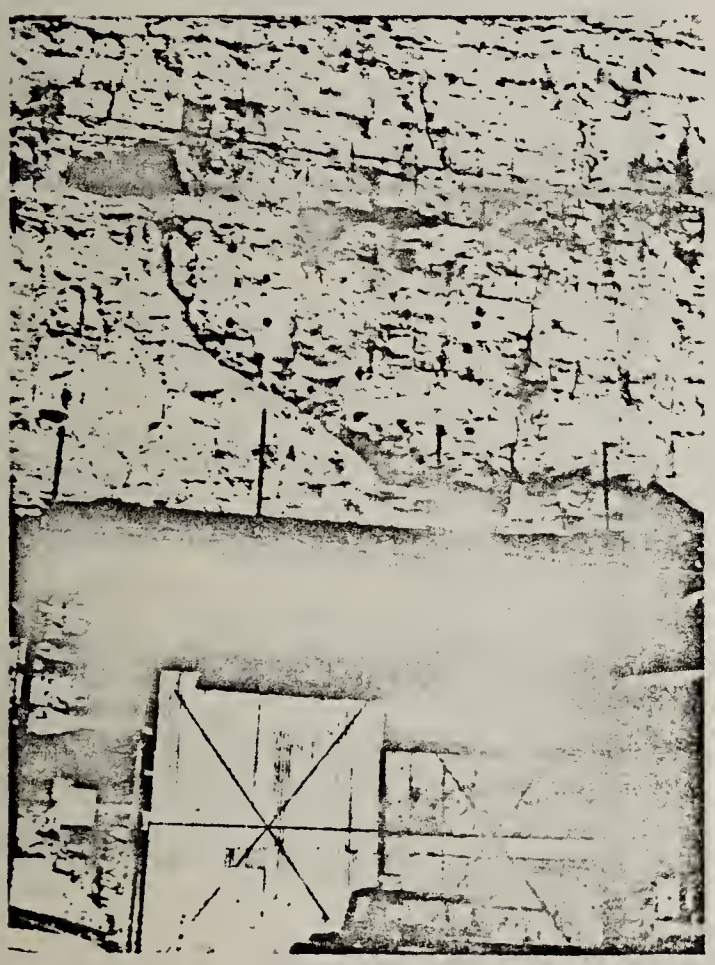
Portal of haulage adit

Roof of haulage adit

Pillar at end of haulage adit



Caved section of vertical cut along mine yard



Vertical cut above adit portal

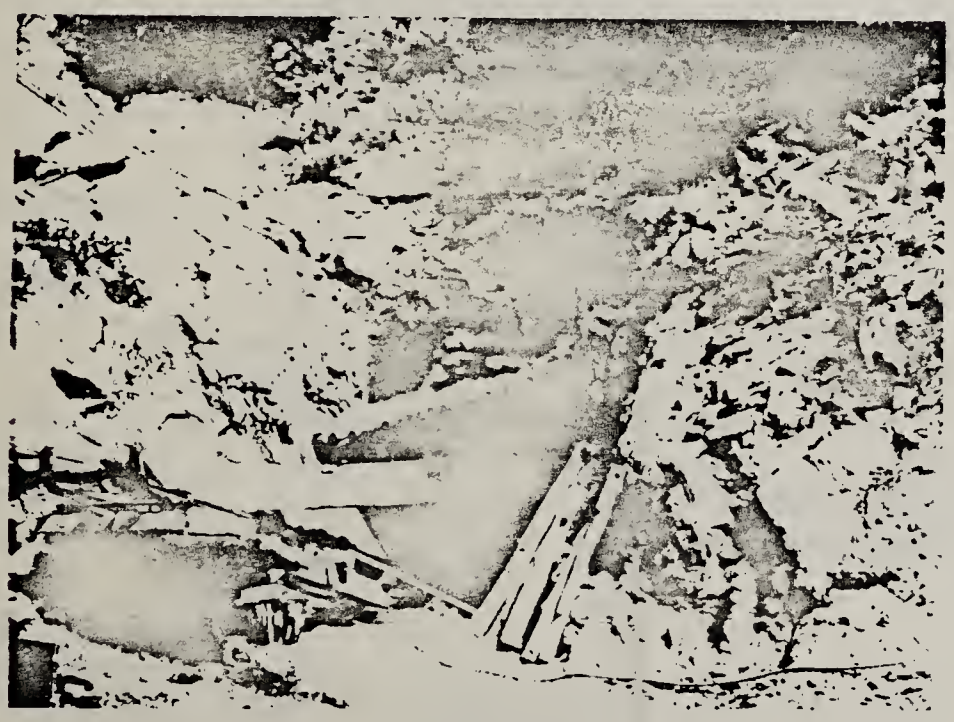
End of haulage adit

60-ft-high bolted pillar

60-ft-high pillar

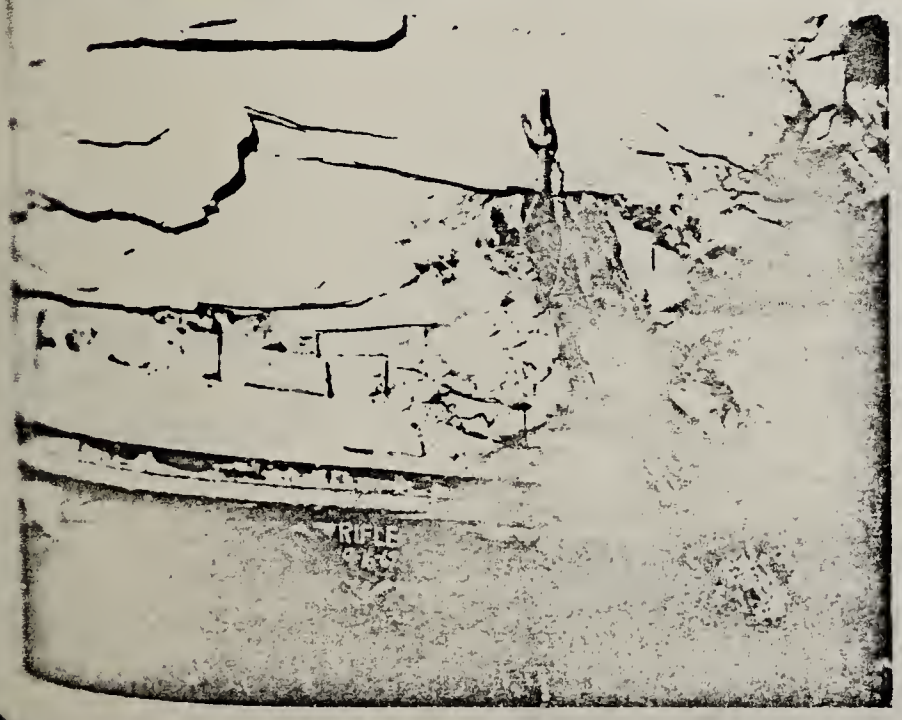
52-ft-wide by 60-ft-high room

Portal of slope entry in steeply pitching coal seam



Pillar on A level at inclined shaft station

Bolted back of incline shaft from A level

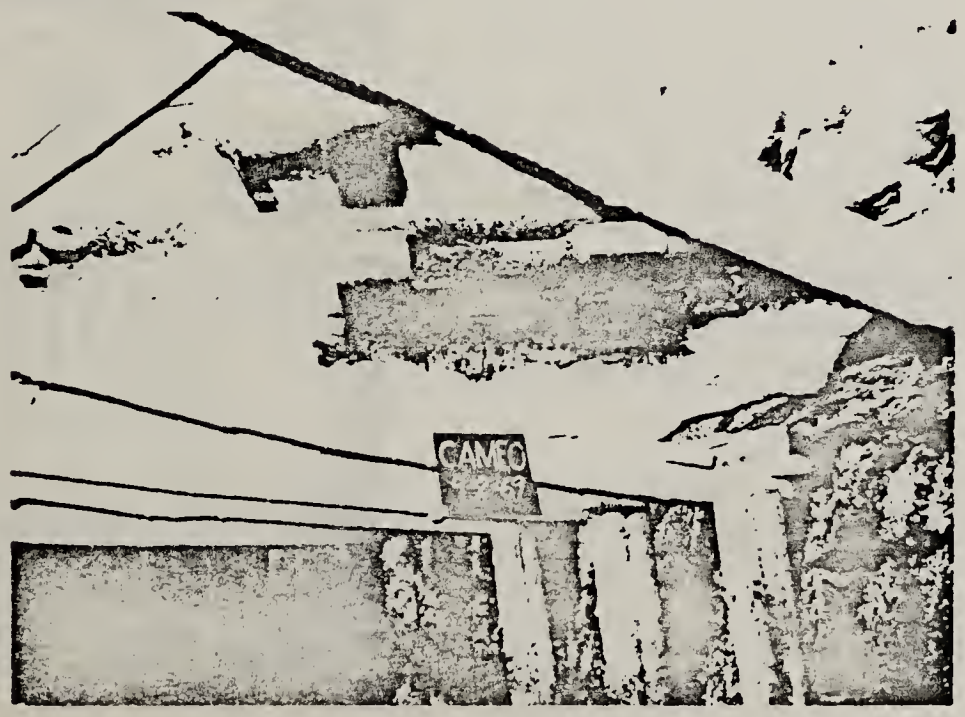


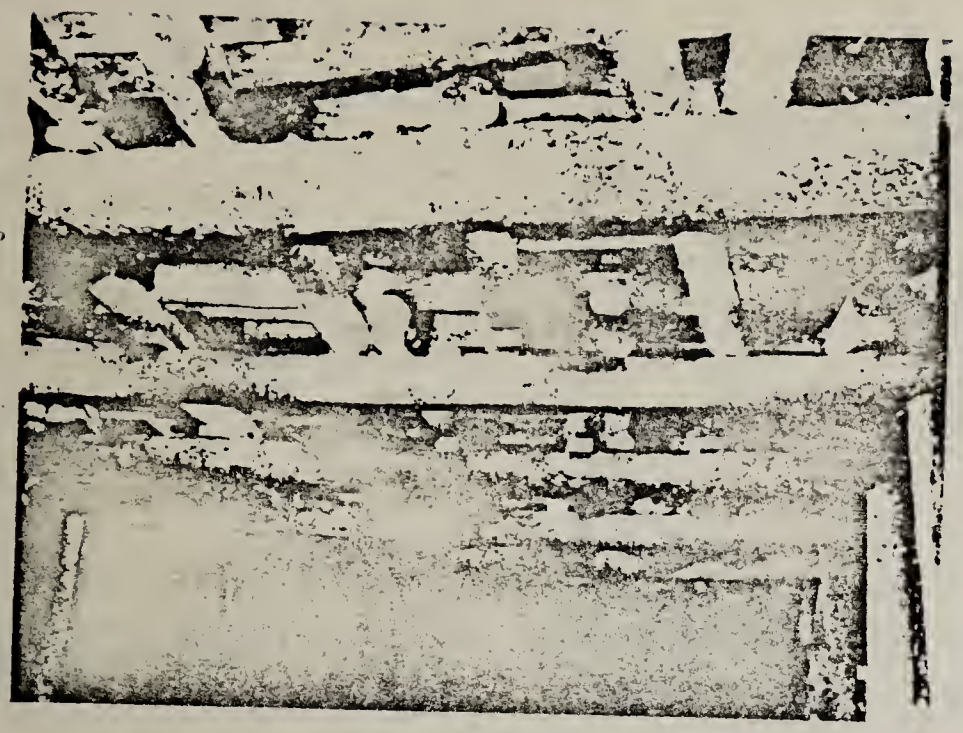
Fractured sandstone above timber set on A level

Portal of main haulage entry

Caved cap rock around roof bolts in 2nd East section

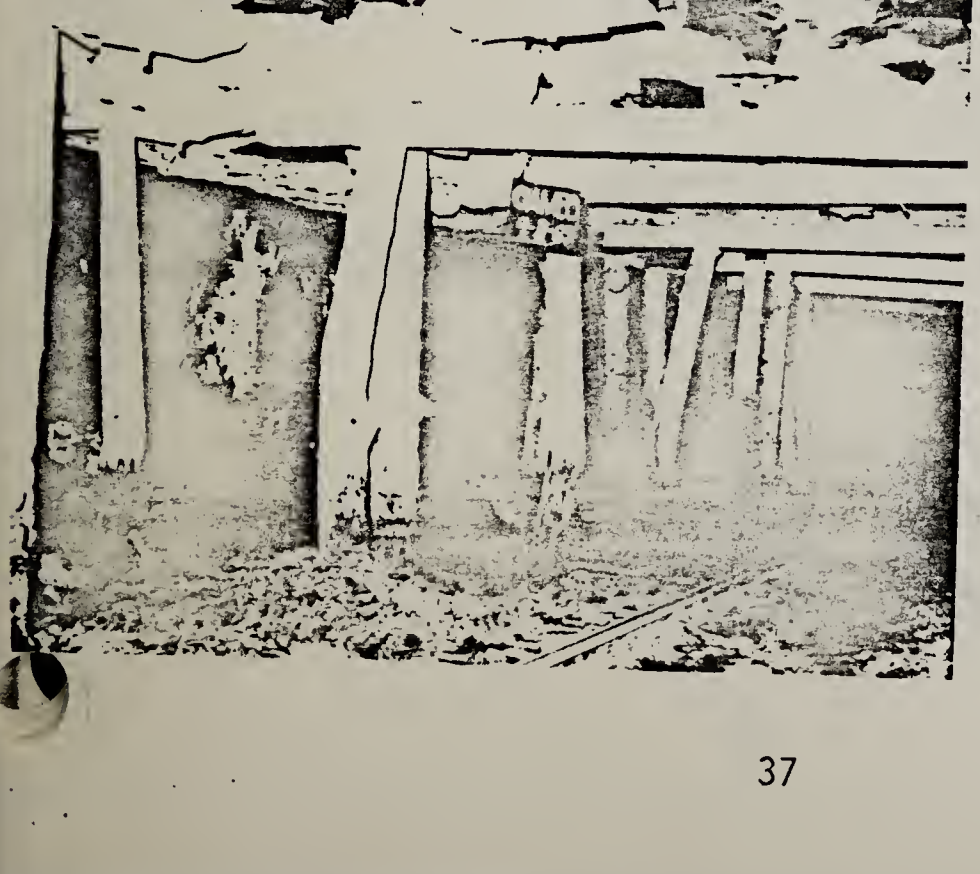
Cap rock and top coal separation along No. 1 Southwest entry





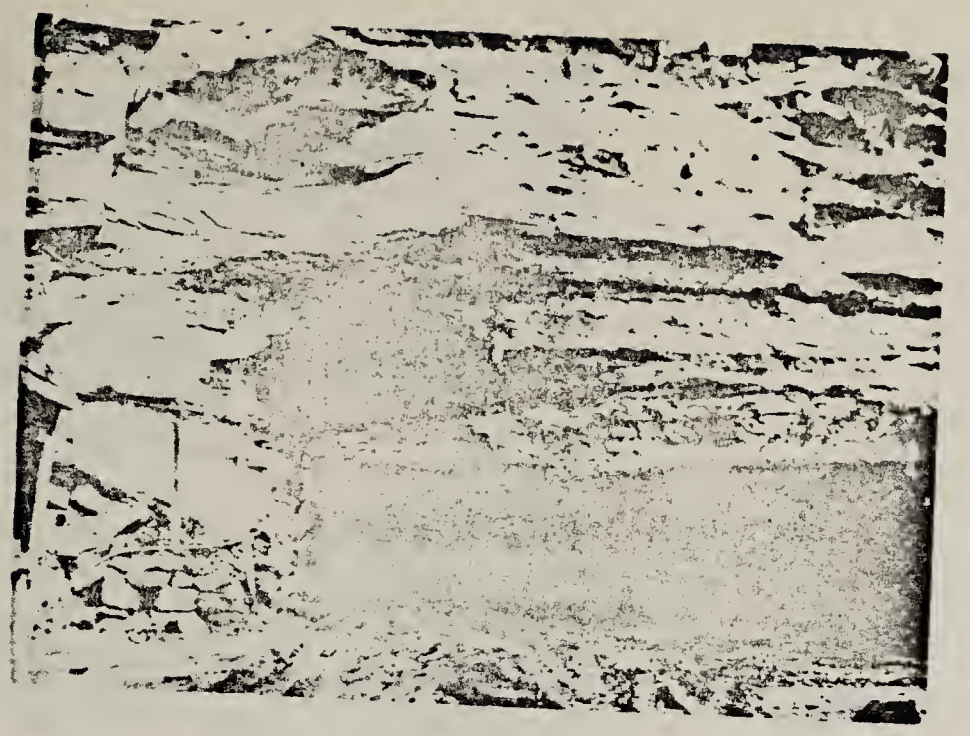
Timber crib in caved alluvium along No. 2 Outside entry

Caved roof of 3rd West haulage entry



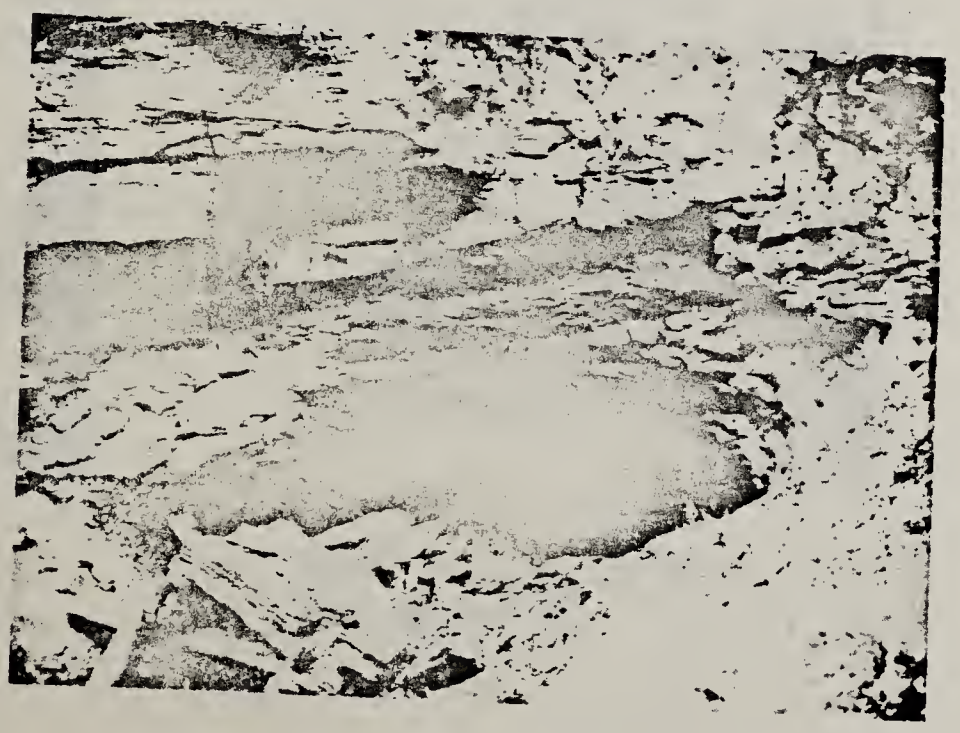
Timbers buckled from roof sag and floor heave in 3rd West haulage entry

Portal of main haulage entry



Portal timber sets of main haulage entry

Portal of return airway and emergency escapeway



Recently caved material in air intake

Toppled post and fallen cap piece in main haulage entry

Caved section of main haulage entry

Part II

WELL EFFECTS EVALUATION

EFFECTS EVALUATION OF GAS WELLS AND ASSOCIATED FACILITIES FOR PROJECT RULISON

by

Don C. Ward 1/

ABSTRACT

At the request of the Effects Evaluation Division of the Atomic Energy Commission's Nevada Operations Office, the Bureau of Mines inventoried gas wells and associated facilities within a 10-mile radius of Rulison surface ground zero (GZ). All wells and facilities within 5 miles of GZ were examined and photographed in detail, both preshot and postshot.

No surface damage from the Rulison detonation was sustained by any of the field gas wells, the test well, or the emplacement well. No subsurface damage was evident or suspected at field wells. It is reasonable to assume that no damage should occur to similar wells and facilities that may be subjected to comparable ground motion.

INTRODUCTION

Historical Description

Project Rulison is a joint experiment sponsored by Austral Oil Company Incorporated, Houston, Texas, the U.S. Atomic Energy Commission and the Department of the Interior, with the Program Management provided by CER Geonuclear Corporation of Las Vegas, Nevada, under contract to Austral. Its purpose is to study the economic and technical feasibility of using underground nuclear explosions to stimulate production of natural gas from the low-productivity, gas-bearing Mesaverde Formation in the Rulison Field.

The nuclear explosive for Project Rulison was detonated successfully at 3:00 p.m. ±0.1 seconds Mountain Daylight Time, September 10, 1969, at a depth of 8,425.5 feet below ground level and was completely contained. Preliminary results indicate that the Rulison device behaved about as expected; i.e., with a yield of 40 (-4 to +20) kt. The wellhead of the emplacement well, Hayward 25-95A, is at an elevation of 8,154 feet above mean sea level (msl) and is located 1,976.31 feet east of west line and 1,813.19 feet north of south line of Section 25, Township 7 South, Range 95 West of 6th P.M., Garfield County, Colorado, which corresponds to geodetic coordinates of longitude 107°56'53" West and latitude 39°24'21" North.

1/ Petroleum Engineer, Bartlesville Petroleum Research Center

Objective

This gas well survey was conducted under the authority of the Nevada Operations Office of the Atomic Energy Commission (AEC). Purpose of this program was to predict the hazards involved, take measures to control or eliminate the identified hazards, if any; and provide documentation of the effects of the Project Rulison detonation. The Bartlesville Petroleum Research Center of the U.S. Bureau of Mines made this investigation.

Background

Previous experience of damage to wells from nuclear detonations, except large-diameter emplacement or water wells at the Nevada Test Site, is limited to the Salmon Event--Project Dribble (1),[2/] Baxterville Field, Miss., and Project Gasbuggy (2), San Juan Basin, N. Mex.

No well or related facility was damaged by the Salmon Event; nor was any damage expected because maximum particle acceleration and velocity recorded in the Baxterville Field were only 0.2 g and 3.0 cm/sec.

No surface damage was sustained from the Project Gasbuggy detonation by any field gas well or by any test well near surface GZ, and no subsurface damage was evident beyond the test-well cluster. Surface peak velocities ranged from 160 cm/sec at the surface above the explosion to about 40 cm/sec at 8,400-foot horizontal distance. Surface peak acceleration was as high as 9.5 g at 1/2 mile from GZ--the distance to the nearest producing well. Subsurface ground motion at shot depth at this distance was estimated at 25 g and 400 cm/sec. The only location of recorded subsurface motions was in an instrument hole, 1,470 feet from GZ, and values were 16.0 g (gages saturated at this value) and 160 cm/sec.

Subsurface damage was encountered during re-entry of a well, stemmed for the Gasbuggy shot, a slant distance of 780 feet from GZ. Motion values at this distance were estimated at about 250 g and 5,000 cm/sec.

SURVEY PROCEDURE

Preliminary Survey

Gas wells and associated facilities in the Project Rulison area were inventoried and reported to the AEC during March 1969. Figure 1 shows locations of gas wells within 10 miles of GZ. Table 1 lists wells within a 5-mile radius of GZ.

2/ Underlined numbers in parentheses refer to items in the list of references at the end of this report.

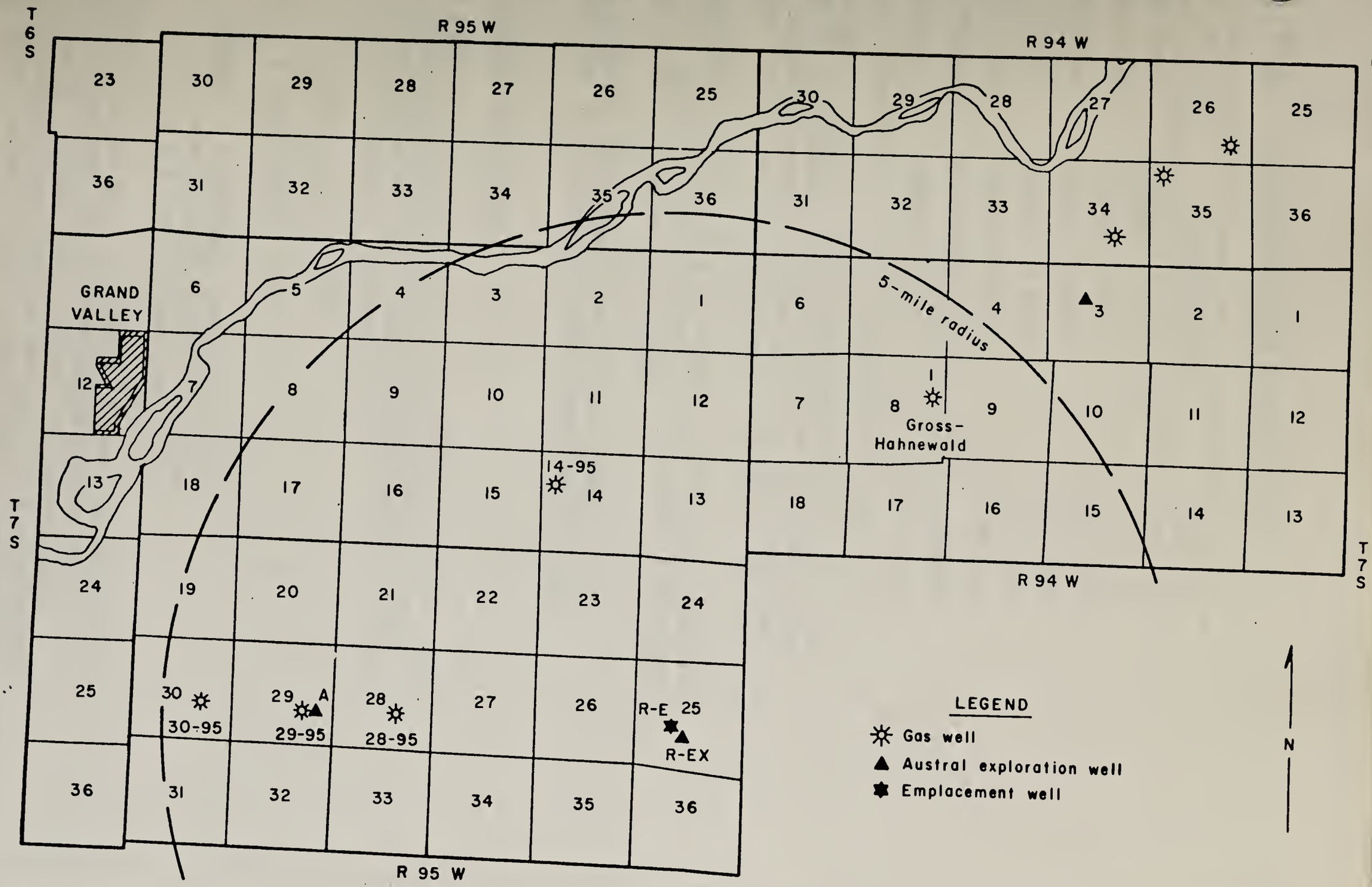


FIGURE 1.- Gas Wells in the Project Rulison Area.

TABLE 1.--Gas wells within 5 miles of GZ

Dist. from GZ	Lease/Well No.	Location
285 feet	Hayward 25-95 (R-EX)	25-7S-95W
2.8 miles	Federal 28-95	28-7S-95W
2.8 miles	Federal 14-95	14-7S-95W
3.6 miles	Federal A 29-95	29-7S-95W
3.8 miles	Federal 29-95	29-7S-95W
4.1 miles	Gross-Hahnewald 1	8-7S-94W
4.8 miles	Federal 30-95	30-7S-95W

ve of the wells listed in table 1 are field gas wells. The 25-95 (R-EX) and Federal A 29-95 are exploratory wells that illed to determine reservoir characteristics for a nuclear tion study. All wells were completed in the Mesaverde formation.

llhead equipment consists of a casinghead, mastergate valve and te manifold. Other surface facilities consist mainly of separa- ydrator units and gas metering equipment.

ste[illegible]ope Gas Co. operates in the Rulison Field a small- r gatnering line that passes no nearer than 2 miles from GZ.

ed Ground Motion and Effects

e expected yield of the Rulison explosive was 40 kilotons. Peak particle acceleration and velocity at the nearest well were d at 0.85 g and 28 cm/sec using the following equations derived buggy data by Environmental Research Corp.:

$$a = 1.26 \times 10^{7} R^{-1.93}$$

$$v = 2.30 \times 10^{8} R^{-1.86}$$

where a = particle acceleration, g
v = particle velocity, cm/sec
R = slant distance, meters

se ground motion values are considerably lower than values at mage to wells, pipelines, and oilfield-type construction expected. Beyond the test well cluster, the nearest pro- ell at Gasbuggy experienced, at the surface, 9.5 g acceleration er than 100 cm/sec velocity with no observable surface or sub-

surface damage. Based on this previous experience, it was recommended that only wells and facilities within 5 miles of Rulison GZ be documented. No damage was predicted and no precautionary measures were considered necessary.

Preshot and Postshot Documentation

A preshot inspection was performed on August 14-15, 1969. All field wells within 5 miles of GZ were examined and photographed. Final documentation of the emplacement well (R-E) and the preshot test well R-EX was accomplished the morning of the detonation.

A postshot inspection was begun approximately 2 hours after detonation. The same facilities as those inspected before detonation were re-examined and rephotographed. Representative photographs appear in the Appendix with accompanying captions and notes. Additional photographs (about 100 were taken) are on file at the Bureau of Mines Bartlesville Petroleum Research Center, Bartlesville, Okla. The preshot and postshot inspections were performed by Bureau of Mines personnel: Don C. Ward and Charles H. Atkinson.

SURVEY RESULTS

Ground Motion and Effects

Data were recorded at 36 seismic instrument stations by the U.S. Coast and Geodetic Survey and were processed by Environmental Research Corp. (3). The seismic station nearest the detonation was 2.1 miles from GZ. Peak surface particle acceleration was recorded at 1.32 g, and peak surface particle velocity was 30.1 cm/sec. These values and those measured values at other stations are in close agreement with predicted values. Therefore the predicted values at the nearest field well should be valid. No subsurface motions were recorded.

No surface damage was sustained by any of the gas wells, the gas pipeline, or by the emplacement well R-E or test well R-EX. No subsurface damage was evident at the field wells. Appraisal of subsurface damage to R-E and R-EX must await re-entry operations, although reservoir pressure is being transferred to the surface through the 10 3/4-inch casing in R-E. The only evidence of movement that resulted from ground motion was the space observed between the 10 3/4-inch casing and the earth fill in the R-E conductor pipe (Photo 4-Appendix).

Conclusions

The safety survey indicates that neither surface nor subsurface damage occurred to any field gas well or related facility. At these distances ground motion values were lower than those at which damage could be anticipated.

No surface damage was observed at R-E and R-EX wells; extent of subsurface damage in these wells is unknown.

Estimated surface motion at Rulison GZ, and motion at the nearest producing well were equal to or less than those at Gasbuggy and at its nearest producing well. Thus, no new damage criteria have been defined. Gasbuggy data show that subsurface damage occurred at ground motion in the range 25 to 250 g and 400 to 5,000 cm/sec.

REFERENCES

1. Ward, Don C. Preshot and Postshot Safety Survey of Oil and Gas Facilities--Baxterville Field, Miss., Salmon Event, Project Dribble. VUF-1022, Final Report. U.S. Atomic Energy Commission, Division of Technical Extension, Oak Ridge, Tenn., Aug. 5, 1965.

2. _____. Safety Survey of Gas Wells and Associated Facilities in the Project Gasbuggy Area -- Part I of PNE-1011 Final Report, Gasfield and Mine Survey. U.S. Atomic Energy Commission Division of Technical Extension, Oak Ridge, Tenn., Sept. 25, 1969.

3. Environmental Research Corp., Observed Seismic Data - Rulison Event - NVO-1163-197. Environmental Research Corp., Alexandria, Va., Nov. 14, 1969.

APPENDIX

The eighteen preshot and postshot photographs included here are typical of the many taken during investigations for the well effects evaluation program. Observed effects of the Rulison event on the seven wells and associated facilities represented by these photographs are summarized immediately below. Well locations are shown on the field map (fig. 1) that accompanies this report.

PHOTO NO.	SUBJECT AND OBSERVED EFFECTS
1-4	Emplacement Well R-E (Ground Zero) - Only evidence of ground motion from event is space visible in photo 4, where earth fill has been displaced from 10 3/4-inch casing.
5-6	Exploratory Well R-EX (285 ft from GZ) - No change evident.
7-10	Well 28-95 (2.8 mi from GZ) - No change evident.
11-12	Well 14-95 (2.8 mi from GZ) - No change evident.
13-14	Well 29-95 (3.8 mi from GZ) - No change evident.
15-16	Gross-Hahnewald Well 1 (4.1 mi from GZ) - No change evident.
17-18	Well 30-95 (4.8 mi from GZ) - No change evident.

Photo 1 - Preshot

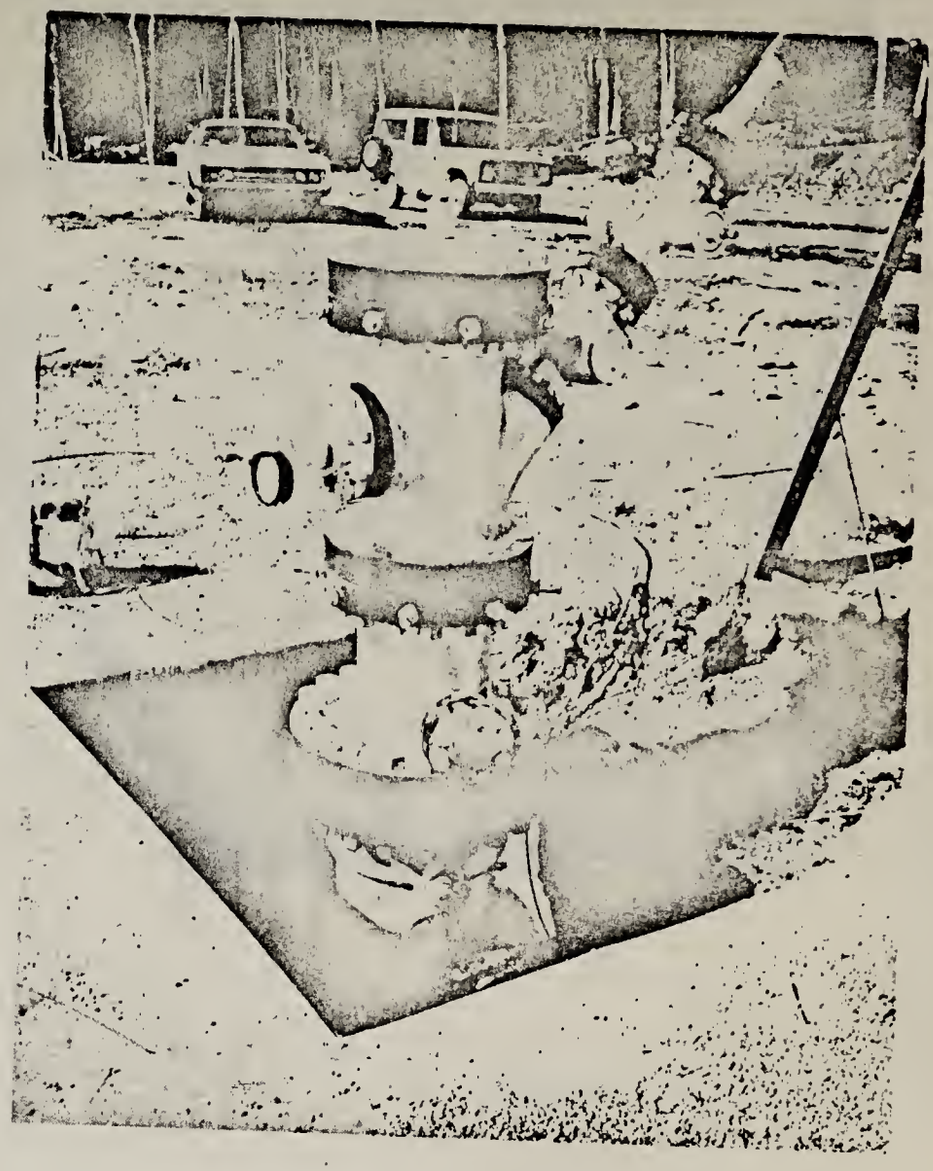


Photo 2 - Postshot

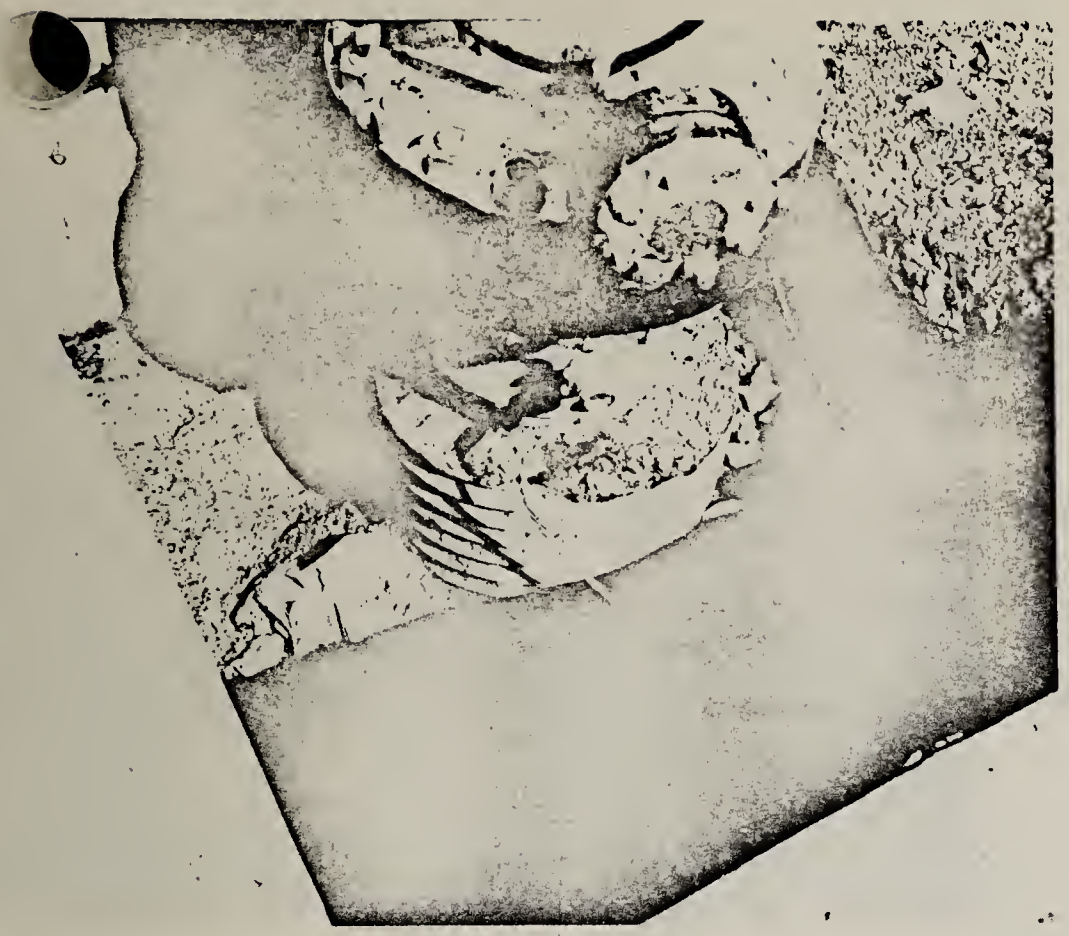


Photo 3 - Preshot

Photo 4 - Postshot

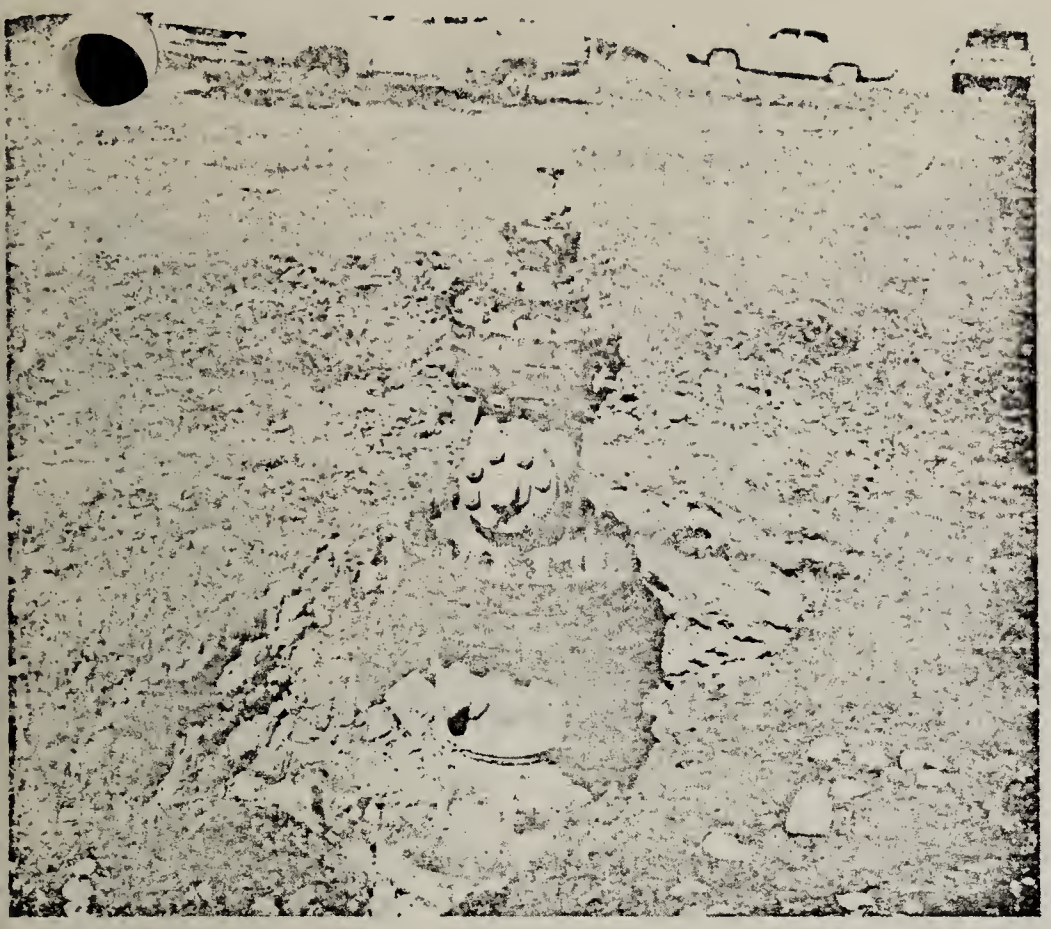


Photo 5 - Preshot

Photo 6 - Postshot

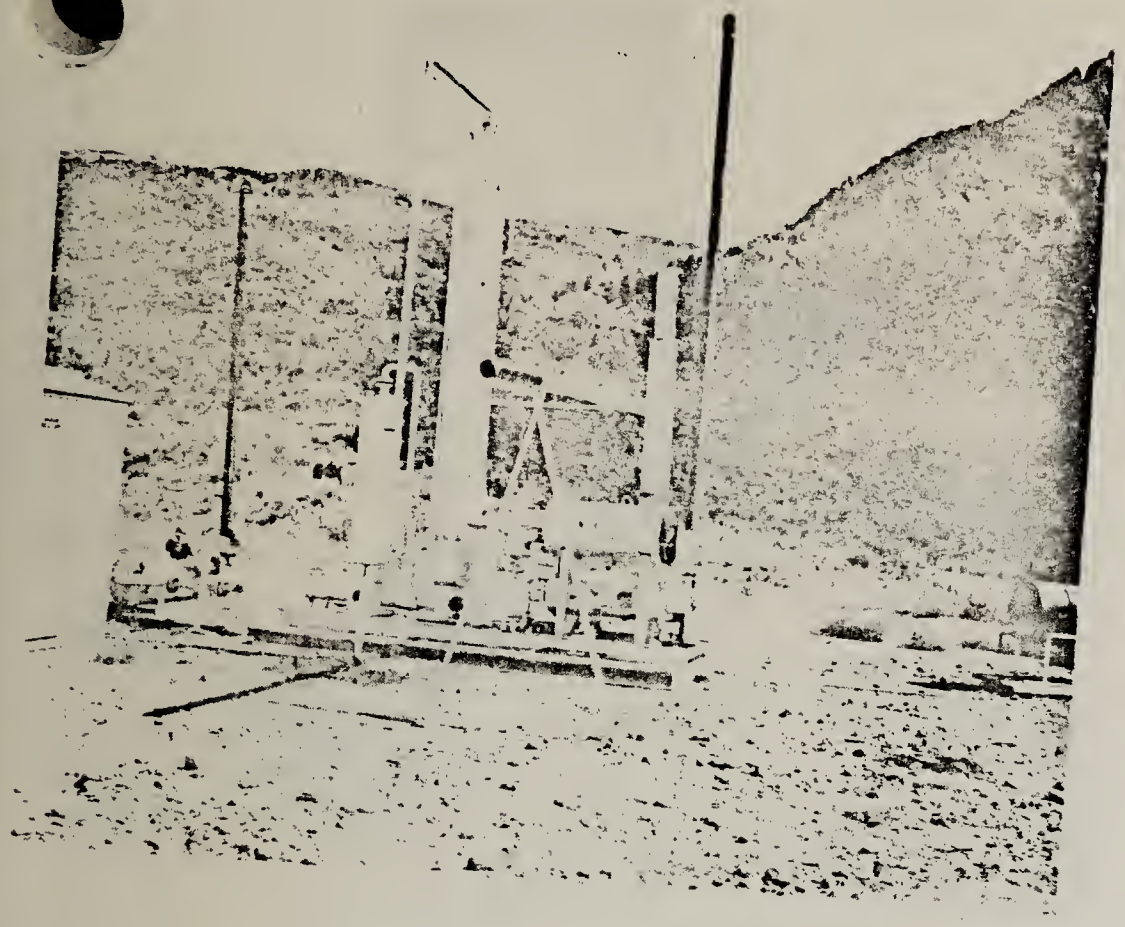


Photo 7 - Preshot

Photo 8 - Postshot

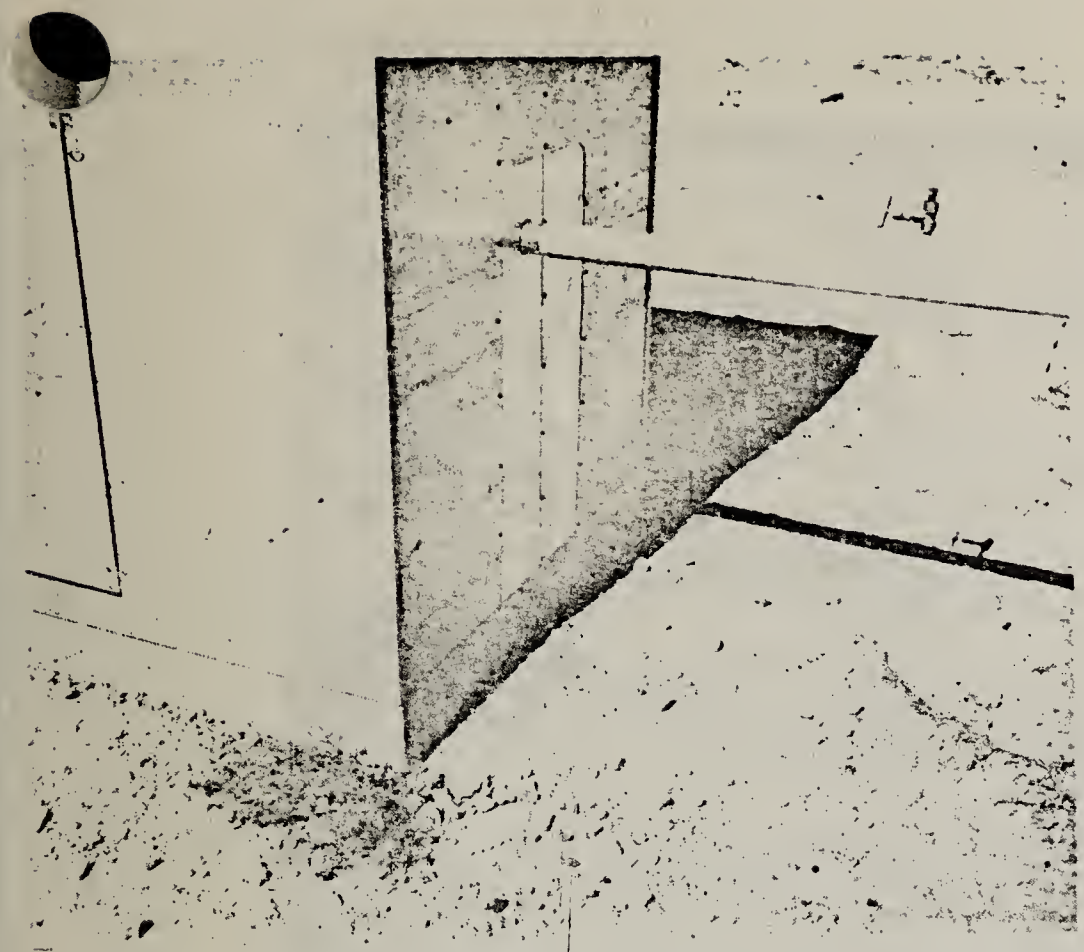


Photo 9 - Preshot

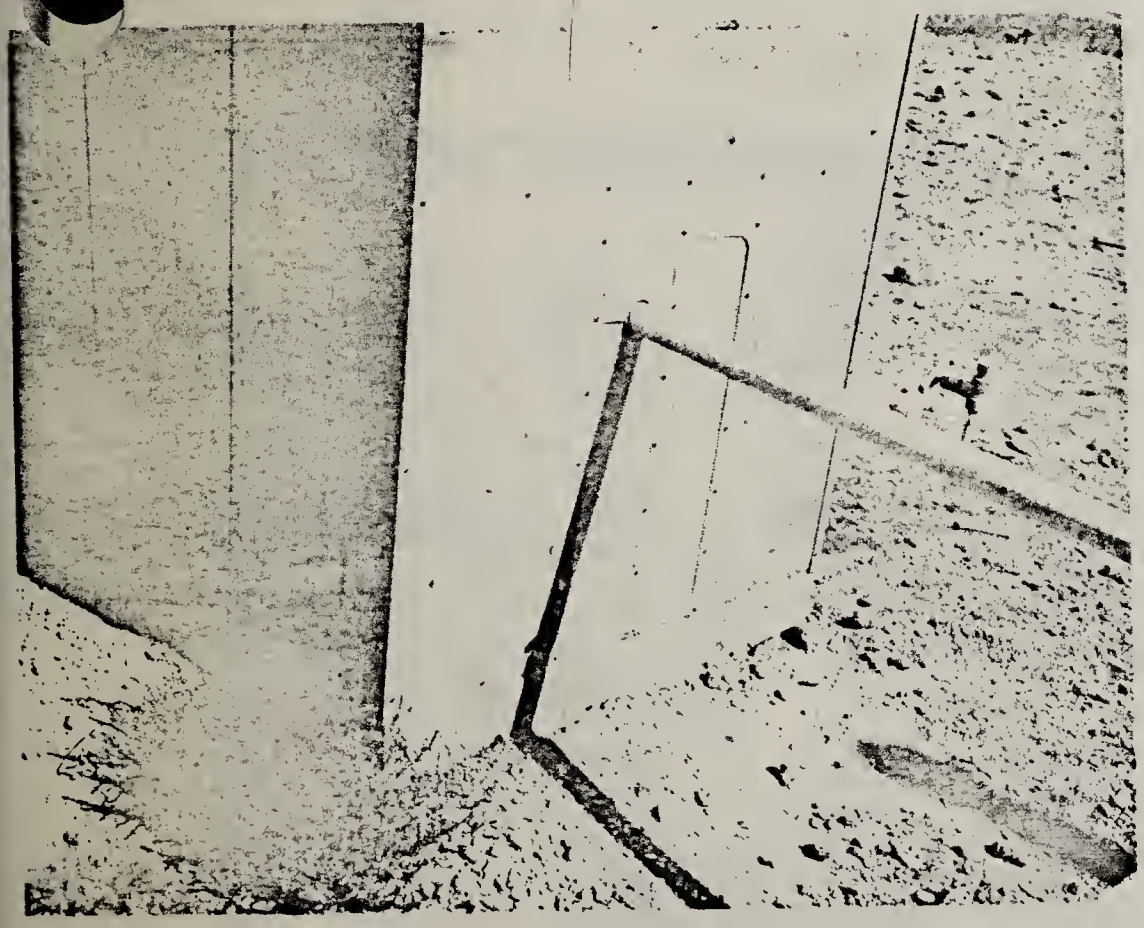


Photo 10 - Postshot

Photo 11 - Preshot

Photo 12 - Postshot

Photo 13 - Preshot

Photo 14 - Postshot

Well 29-95

Photo 15 - Preshot

Photo 16 - Postshot

Photo 17 - Preshot

Photo 18 - Postshot